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RESEARCH ARTICLE

A Neurophysiological Analysis of Fish Species Name Memory According to Image- and Text-Based Instructional Material Presentation: Focusing on Theta and Alpha Band Relative Power Spectra

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ABSTRACT

The purpose of this study is to know about the effective information type to learning through emerged brain activation during carrying out fish specific name memorization task with a different information type. Measuring brain wave test task is composed of both standard task and fish specific name memorization task. The or A Standard task is composed of the activation that is looking the screen motionlessly and writing the sentence correctly presented on the screen. And fish specific name memorization task is developed with memorizing and recollecting fish specific name when given only text information or text and picture information. In this study, 8 students of Mungyeong girls high school took part. In study result, students recollected more fish specific name when carrying out picture and text task than text task. And as a result of analyzing EEG activation difference, Theta-band activation was not seen a meaningful difference when students memorized fish species name. But in the case of students recalled fish species names, the activation decreasing width of theta-band in the parietal lobe decreased when students conducted picture and textual task than only textual task. In case of alpha-band, when students memorized fish species names, the activation decreasing width in the frontal lobe decreased when students conducted picture and textual task so it is decreased in the whole brain. Also when students recalled fish species names activation of alpha-band in parietal lobe increased so it is increased in the whole brain. Through this research result, we provided basic material about efficient information type in student's studying and raise necessity of a follow-up research.

Keywords: material presentation type, memorization, EEG activation, relative power spectral analysis, brain region

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Introduction

In contemporary society, advances in science and technology have enabled students to use learning materials composed of various combinations of textual information and visual elements, such as illustrations, graphs, and diagrams. Within this changing learning environment, students perceive that the effectiveness of learning materials varies according to individual preferences. Some students report that learning with text-only materials allows them to maintain better attention, whereas others perceive that materials combining images with related textual information enhance attention to the content and support longer retention of learned information.

In response to these perceptions, numerous educational researchers have investigated how different formats of instructional material presentation influence learners' cognitive processes and learning outcomes. Kwon et al. (2012) reported that visual elements such as illustrations positively affect learners' attention and learning motivation, thereby facilitating understanding and memory of instructional content. Ryu and Jung(2013) demonstrated that learners' cognitive load decreases when text and images are presented in close spatial proximity and when the content of the text is semantically consistent with the visual information. Similarly, Park et al. (2012) found that when images and related textual information are presented simultaneously and in close spatial proximity while considering learners' cognitive levels, extraneous cognitive load induced by instructional methods decreases, whereas intrinsic cognitive load related to learners' cognitive processing for task performance increases. Furthermore, Mayer and Moreno (1999, 2002) empirically showed that closer spatial proximity between illustrations and accompanying text facilitates integration between visual and verbal information, resulting in improved learning outcomes.

However, prior studies examining the effects of instructional material presentation formats, as well as studies based on learners' perceptions, have primarily employed cognitive psychological research methods such as interviews, questionnaires, and behavioral observations. Although these approaches are effective in comparing learning outcomes and achievement levels, they are limited in explaining the underlying cognitive processes and information-processing mechanisms that give rise to differences in learning performance. During task performance, learners engage in various cognitive processes—including attention allocation, information integration, memory encoding, and retrieval—which are fundamentally grounded in neural activation. Moreover, behavioral characteristics such as perceived cognitive stability and concentration during task performance can be interpreted through changes in brainwave activation(Jung & Yun, 2008; Kim et al., 2016; Kwon & Lee, 2010; Lee et al., 2003).

Against this backdrop, researchers have increasingly adopted neurophysiological methods to obtain richer interpretations of neural activation underlying human behavior and cognition. Neurophysiological techniques include EEG, fMRI, MEG, and PET; among these, electroencephalography (EEG) is widely used due to its relatively simple operation, low cost, flexibility in measurement settings, and noninvasive nature. In addition, EEG offers high temporal resolution, making it particularly suitable for examining rapid changes in cognitive processing during task performance. Because distinct frequency bands exhibit characteristic activation patterns depending on cognitive demands, EEG provides a useful means for interpreting cognitive processes through changes in brain activation (Jung & Yun, 2008; Kim & Jung, 2016).

Previous studies investigating the meaning of EEG activation in cognitive and learning contexts have reported that changes in specific frequency bands are closely associated with the level of cognitive processing required during task performance. Among these, theta and alpha bands have been widely used as key indicators reflecting thinking processes, attention, cognitive stability, and cognitive load during learning tasks.

Theta-band activation has been reported to increase when cognitive processing becomes more demanding during task performance. Hutchison (1996) and Klimesch (1995) observed changes in theta-band activation in situations involving increased memory demands and cognitive processing requirements, while Fairclough et al. (2005) identified theta-band changes under conditions of heightened cognitive load. Domestic studies have similarly analyzed theta-band activation as a frequency band showing meaningful changes during tasks involving scientific reasoning, problem solving, and creative thinking (Kim & Jung, 2010; Kim & Jung, 2015; Kim & Jung, 2016). These findings suggest that theta-band activation serves as an appropriate indicator for examining neural activation associated with cognitive engagement during learning tasks.

Alpha-band activation has been reported to be related to cognitive stability and attentional states during task performance. Klimesch (1999) suggested that changes in alpha-band activation reflect cognitive processing states, while Sauseng et al. (2005) and Fink et al. (2005) reported that alpha-band activation varies in relation to attentional regulation and cognitive tension. In domestic studies, alpha-band activation has been used as an indicator for interpreting learners' concentration and cognitive burden during learning tasks (Jung & Yun, 2008; Kim & Jung, 2016). In particular, differences in alpha-band activation according to instructional formats and task types have been used to compare learners' perceived cognitive stability and burden.

In contrast, within the scope of prior studies reviewed in the present research, beta- and gamma-band activities have been less frequently employed as indicators directly explaining differences in memory performance or cognitive load associated with instructional material presentation formats. Accordingly, the present study restricts its EEG analysis to theta and alpha bands, which have been repeatedly validated in prior research as relevant to learning and cognitive task performance. This selection is therefore methodologically appropriate and aligned with the objectives of the study.

With respect to EEG data analysis, two representative approaches include absolute power spectrum analysis and relative power spectrum analysis. Absolute power spectrum analysis quantifies the absolute magnitude of EEG activation within each frequency band, whereas relative power spectrum analysis calculates the proportion of each frequency band relative to total EEG power. Because EEG measurements can be influenced by individual differences such as skull thickness, hair density, and electrode–scalp contact conditions, relative power spectrum analysis is considered more effective in reducing such variability. Consequently, many researchers have employed relative power spectrum analysis to investigate neural activation related to cognitive processes (Jung & Yun, 2008; Kim et al., 2005).

Furthermore, to interpret EEG activation changes during task performance more clearly, additional analytical approaches are required. Learners engage in different types of cognitive processing depending on task characteristics, including the integration of visual, auditory, and sensory information. As a result, baseline EEG activation in non-task conditions may vary across task types. To account for this, brain activation difference analysis has been proposed, in which EEG activation during the target task is compared with EEG activation during a baseline task. This approach has been shown to be effective for examining cognitive processes associated with task performance (Kim & Jung, 2010; Kim & Jung, 2015; Lee et al., 2016).

Accordingly, the present study aims to analyze differences in learning performance and EEG relative power spectrum activation while students memorize and recall fish species names using text-only instructional materials and image-plus-text instructional materials. By examining differences in relative power spectrum activation across task types, this study seeks to provide neurophysiological evidence for the effects of instructional material presentation formats and to offer empirical implications for designing more effective learning materials.

Materials and Methods

Participants

This study involved 12 first-year female high school students(aged 16) enrolled in a girls' high school located in Mungyeong, Republic of Korea. All participants were physically and mentally healthy and had no identified cognitive or psychological disorders. Prior to EEG measurement, the participants were fully informed that EEG recording is completely harmless to the human body, and they were instructed on precautions to be observed during the measurement process.

Among the participants, three students were excluded from EEG data analysis due to excessive artifacts that made data analysis impossible, and one student was excluded due to insincere participation in the EEG behavioral tasks. Consequently, EEG data from a total of 8 students were ultimately used for analysis.

Procedure

The research procedure consisted of the following steps: analysis of prior studies, development of measurement tasks, pre-training for EEG measurement, task performance with EEG recording, analysis of relative power spectrum activation differences, and statistical analysis.

First, the tasks were developed and categorized into two types of EEG measurement tasks and one training task, each consisting of three sets. The EEG measurement tasks included a text-only task, composed solely of textual information, and an image-plus-text task, in which visual information and related textual information were presented simultaneously. To enhance participants' familiarity with the EEG measurement tasks, a training task with the same structure as the measurement tasks was developed.

Participants completed the training task once over a duration of 29 minutes, allowing them to become familiar with the task procedures and the precautions required during EEG recording. After donning an integrated electrode cap for EEG data collection, participants confirmed their comfort level through a brief consultation with the researcher. EEG signals were then recorded while participants performed the EEG measurement tasks for 29 minutes.

For EEG analysis, data were preprocessed to identify and remove artifacts. To examine the statistical significance of differences in brain activation, an independent samples t-test was conducted.

EEG Measurements Tasks

The EEG measurement tasks consisted of a baseline task and a fish species name memory task. Both tasks required participants to memorize and recall information presented on a screen. The baseline task was designed to measure background EEG activation generated during task performance and involved copying text presented on the screen onto paper (Fig. 1).

The fish species name memory task consisted of activities in which participants memorized and recalled eight fish species names using two types of learning materials: a text-only format, composed solely of textual information, and an image-plus-text format, composed of visual information along with corresponding textual information (Fig. 2).

To minimize errors arising from experiential recall—where participants rely on prior knowledge rather than information acquired during task performance—200 fish species names that students were unlikely to have previously encountered were selected. Of these, 100 fish species names were extracted as text-only information, and the remaining 100 were extracted as combined image-plus-text information. The visual materials consisted of detailed fish illustrations provided by the online fish encyclopedia (http://fishillust.com/ fish_guide_2), based on scientific illustrations by Kim (2011).

For the development of the text-only task, 48 fish species names were selected from the 100 text-only task, and for the image-plus-text task, 48 items were selected from the 100 image-plus-text items. The remaining fish species names not used in the development of the memory tasks were utilized for the training task. All terms used in the tasks were randomly selected and organized.

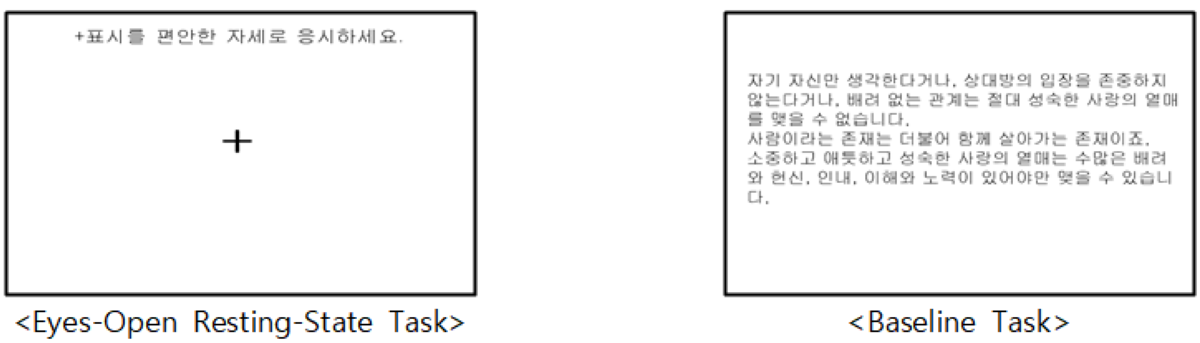

Fig. 1. Examples of the Eyes-Open Resting-State and the Baseline Task

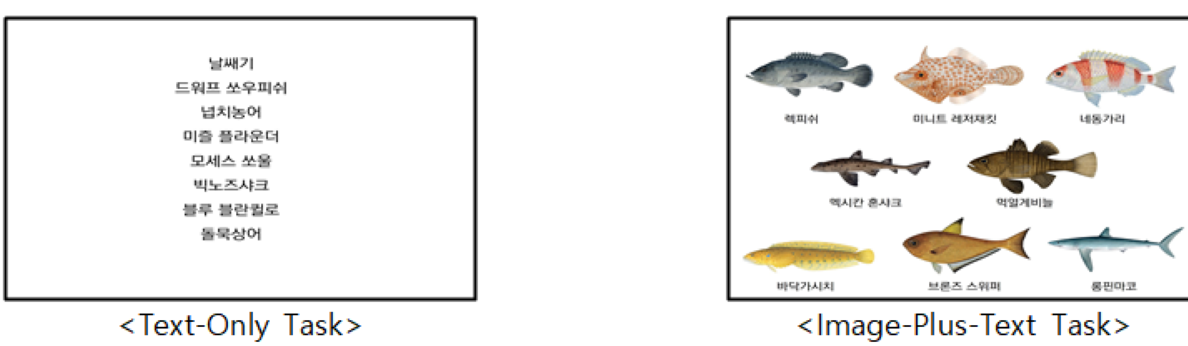

Fig. 2. Examples of Text-Only and Image-Plus-Text Tasks

Task Presentation Procedure

The task execution procedure is illustrated in Fig. 3. As shown in Fig. 3, to enhance participants' psychological stability and their adaptation to wearing the EEG cap electrode system—given that the EEG measurement environment was unfamiliar to them—EEG signals were first recorded for 1 minute under an eyes-closed resting state.

Subsequently, to establish a baseline for identifying EEG activation during the fish species name memory task, EEG signals were recorded for 1 minute under an eyes-open resting state. In addition, to serve as a baseline for identifying EEG activation during the fish species name recall task, EEG signals were recorded for 30 seconds while participants performed the baseline task.

One set of the fish species name memory task consisted of four tasks, and a total of three sets (12 tasks) were administered. To minimize potential errors arising from repeated exposure to similar task types, the order of tasks within each set was randomized.

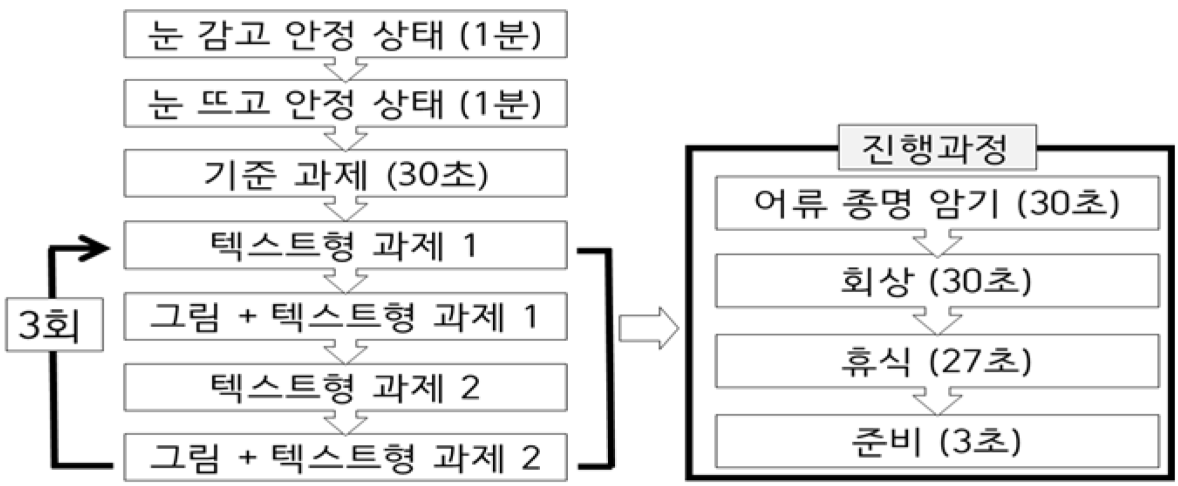

Fig. 3. Task Performance Procedure

Through the training task, participants were thoroughly familiarized with the start and end points of the fish species name memory and recall tasks. Accordingly, during the main experiment, tasks were conducted solely based on on-screen instructions without additional verbal guidance. While memorizing fish species names, participants were instructed to remain seated in a proper posture, refrain from speaking or moving, and focus solely on the information presented on the screen. During the recall phase, participants directly recorded their responses on an answer sheet.

To reduce fatigue and cognitive load that might result from continuous task performance while wearing the EEG cap, rest periods were provided: 30 seconds after each task and 1 minute after the completion of each set. Including rest periods, the total duration of each set was 8 minutes, and the overall task duration was 29 minutes.

EEG Measurement and Analysis Methods

In this study, EEG data were recorded using the E-Series EEG system manufactured by Compumedics(Australia), and EEG signals were collected using ProFusion EEG software(Compumedics, 2002). For EEG recording, participants wore a 32-channel Quik-Cap (Neuroscan) with electrodes positioned according to the international 10–10 electrode placement system.

The electrodes used in this study included M1 and M2 reference electrodes to correct for hemispheric asymmetry, EOL and EOR electrodes to detect muscle artifacts such as eye blinks, and electrodes for recording EEG activation during task performance. These electrodes covered the frontal lobe regions (Fp1, Fp2, F3, F4, F7, F8, Fz, FC3, FC4, FT7, FT8, FCz), the parietal lobe regions (C3, C4, Cz, CP3, CP4, CPz, P3, P4, Pz), the temporal lobe regions (T7, T8, TP7, TP8, P7, P8), and the occipital lobe regions (O1, O2, Oz).

The EEG recording parameters were set as follows: a sampling rate of 256 Hz, electrode–scalp impedance maintained below 10 kΩ, a high-pass filter at 1 Hz, a low-pass filter at 70 Hz, and a notch filter at 60 Hz.

EEG analysis was conducted using 20-second segments of EEG data that were judged to be minimally contaminated by artifacts such as eye blinks, muscle movements, and electrical noise. These segments were extracted from EEG recordings obtained during the eyes-open resting state, baseline task performance, and fish species name memory and recall tasks.

Relative power spectrum analysis was employed to calculate the ratio of power in each frequency band relative to the total power across all frequency bands. The frequency bands analyzed were theta(4.0–7.9 Hz) and alpha(8.0–12.9 Hz). These frequency bands were selected based on prior research indicating that theta and alpha activation are closely associated with creative thinking and mental relaxation.

Because EEG activation during the baseline task varied across participants, EEG activation difference values were calculated to isolate task-specific neural activation. Specifically, for each brain region, the relative power spectrum values during the fish species name memory task were subtracted from those obtained during the baseline task, and the resulting activation difference values were visualized graphically. Positive activation difference values indicated increased EEG activation, whereas negative values indicated decreased activation.

To examine the statistical significance of differences in the number of fish species names recalled across task types, an independent samples t-test was conducted using the results from six tasks per task type performed by each of the eight participants. EEG analysis was based on EEG data collected from 30 electrodes while the eight participants performed six tasks for each task type, as summarized in Table 1.

Table 1. Information on the amount of data used for statistical analysis

Task Type		N	Basis for Calculation (Number of Participants × Number of Tasks × Number of EEG Channels)
Fish Species Name Recall Analysis	Text-Only Task	48	8 participants × 6 tasks
	Imag e-Plus-Text Task	48	8 participants × 6 tasks
EEG Analysis	Text-Only Task	1,440	8 participants × 6 tasks × 30 channels
	Imag e-Plus-Text Task	1,440	8 participants × 6 tasks × 30 channels

Basis for Calculation :(Number of Par ticipants × Number of Tasks × Number of EEG Channels

Results

Fish Species Name Recall Performance by Task Type

Fig. 4 presents the mean number of fish species names correctly recalled by task type to examine whether recall performance differed across learning material formats. Students who completed the text-only task recalled an average of

2.42 fish species names (SD=0.92), whereas those who completed the image-plus-text task recalled an average of 2.77 fish species names (SD=0.93).

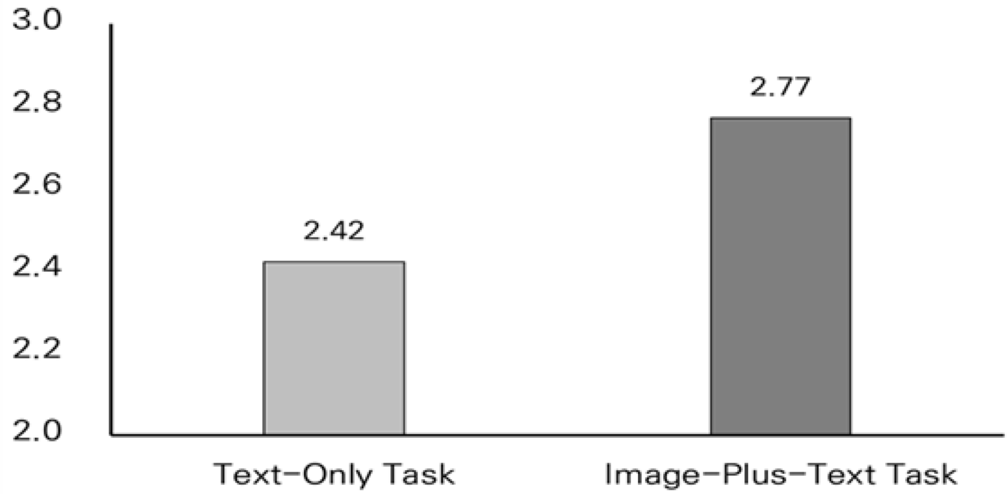

Fig. 4. Mean number of recalled fish species names

To examine the statistical significance of the difference observed in Fig. 4, an independent-samples t test was conducted, and the results are presented in Table 2. The analysis indicated that the difference in recall performance between task types reached a trend-level significance (t=-1.879, *p*=.063), with higher recall scores observed in the image-plus-text condition (p<.10). As the result did not meet the conventional significance threshold of *p*<.05, the effect size (Cohen's *d*) was additionally calculated to more closely examine the magnitude of the difference between conditions. The resulting effect size was approximately d≈0.38, indicating a small-to-moderate effect.

Table 2. Statistical results of fish species name recall

Task Type	N	Mean	SD	t	p-value
Text-Only Task	48	2.42	0.919	-1.879	0.063*
Image-Plus-Text Task	48	2.77	0.928		

$^{*}p<.1$

Theta-Band Activation Differences by Task Type

Theta-Band Activation Differences According to Task Type During Fish Species Name Memory

Figure 5 displays topographical mappings of theta-band (4.0–7.9 Hz) relative power changes during fish species name memorization, computed as activation differences relative to the baseline task. During memorization using text-only materials, theta activation was highest in the frontal lobe (M=0.0471, SD=0.1733), followed by the temporal lobe (M=0.0152, SD=0.1111) and the parietal lobe (M=0.0121, SD=0.1052), and lowest in the occipital lobe (M=-0.0252, SD=0.1005). A similar spatial pattern was observed during memorization using image-plus-text materials (frontal lobe: M=0.0502, SD=0.1597; temporal lobe: M=0.0183, SD=0.0935; parietal lobe: M=0.0183, SD=0.0954; occipital lobe: M=-0.0199, SD=0.1050).

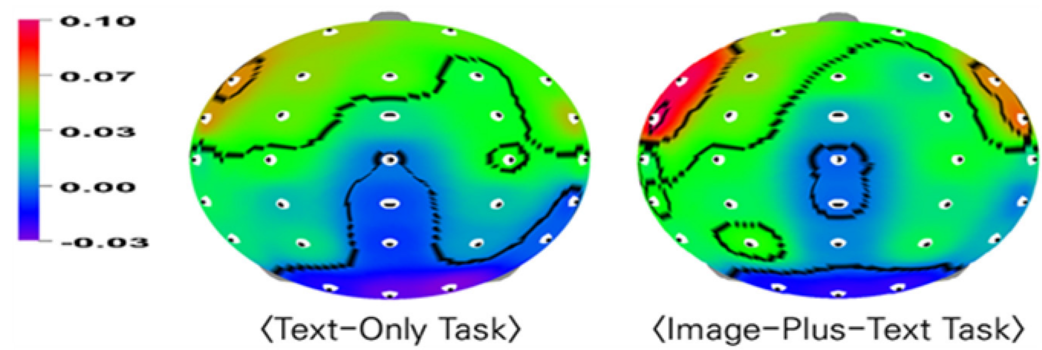

Fig. 5. Theta band activation during fish species name memory

Independent-samples t-tests revealed no statistically significant between-condition differences in theta-band relative power during memorization at the regional level or at the whole-brain level (Table 3).

Table 3. Theta relative power differences during fish species name memory

Brain region	N	Text-Only Task		Image-Plus-Text Task		t	p-value
		Mean	SD	Mean	SD		
Frontal lobe	576	0.0471	0.1733	0.0502	0.1597	-0.312	0.755
Parietal lobe	432	0.0121	0.1052	0.0183	0.0954	-0.907	0.365
Temporal lobe	288	0.0152	0.1111	0.0183	0.0935	-0.358	0.720
Occipital lobe	144	-0.0252	0.1005	-0.0199	0.1050	-0.433	0.665
Total	1440	0.0230	0.1389	0.0272	0.1274	-0.850	0.395

Analysis of Theta-Band Activation Differences According to Task Type During Fish Species Name Recall

Fig. 6 presents theta-band activation patterns during recall. During recall following the text-only task, theta activation was highest in the temporal lobe (M=0.0254, SD=0.1041), followed by the parietal lobe (M=-0.0325, SD=0.0758), the occipital lobe (M=-0.0463, SD=0.0772), and frontal lobe (M=-0.0591, SD=0.1382). During recall following the image-plus-text task, a similar ordering was observed (temporal lobe: M=0.0263, SD=0.1081; parietal lobe: M=-0.0231, SD=0.0812; occipital lobe: M=-0.0456, SD=0.0804; frontal lobe: M=-0.0593, SD=0.1456).

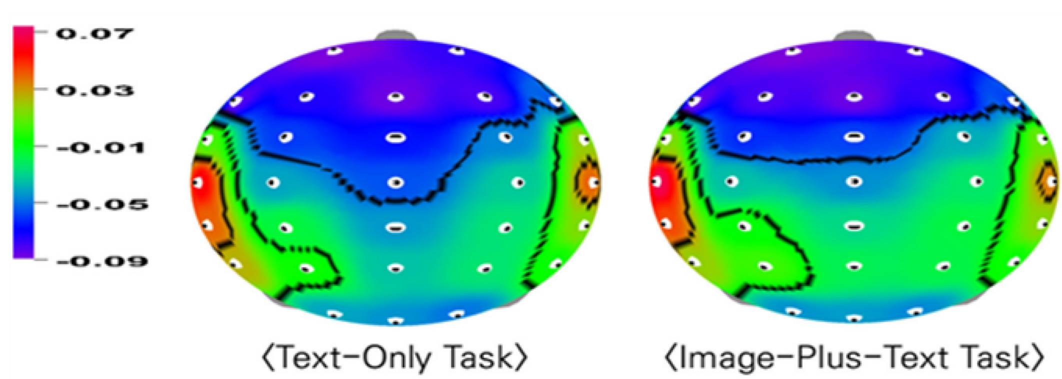

Fig. 6. Theta band activation during fish species name recall

An independent-samples t test revealed a marginal difference between task types in the parietal lobe during the recall phase (t=-1.764, *p*=.078), with relatively higher theta-band activation observed in the image-plus-text condition (*p*<.10). No significant differences were found in the other regions or at the whole-brain level (Table 4). In addition, the effect size (Cohen's *d*) for the task-type difference in the parietal lobe was calculated and yielded a value of d≈0.12, indicating a very small effect size.

Table 4. Theta relative power differences during fish species name recall

Brain region	N	Text-Only Task		Image-Plus-Text Task		t	p-value
		Mean	SD	Mean	SD		
Frontal lobe	576	-0.0591	0.1382	-0.0593	0.1456	0.024	0.981
Parietal lobe	432	-0.0325	0.0758	-0.0231	0.0812	-1.764	0.078*
Temporal lobe	288	0.0254	0.1041	0.0263	0.1081	-0.094	0.925
Occipital lobe	144	-0.0463	0.0772	-0.0456	0.0804	-0.070	0.944
Total	1440	-0.0329	0.1144	-0.0299	0.1201	-0.682	0.496

*$p < 0.1$

Alpha-Band Activation Differences by Task Type

Alpha-Band Activation Differences According to Task Type During Fish Species Name Memorization

Fig. 7 shows alpha-band(8.0–12.9 Hz) relative power changes during memorization. During the text-only task, alpha activation was highest in the frontal lobe(M=−0.0183, SD=0.0525), followed by the temporal lobe(M=-0.0191, SD=0.0566), the occipital lobe(M=-0.0227, SD=0.0472), and the parietal lobe(M=-0.0324, SD=0.0568), with a whole-brain mean of −0.0231(SD=0.0545). During the image-plus-text task, alpha activation was highest in the frontal lobe(M=-0.0067, SD=0.0512), followed by the temporal lobe(M=-0.0223, SD=0.0547), the occipital lobe(M=-0.0280, SD=0.0382), and the parietal lobe(M=−0.0331, SD=0.0464), with a whole-brain mean of -0.0199(SD=0.0506).

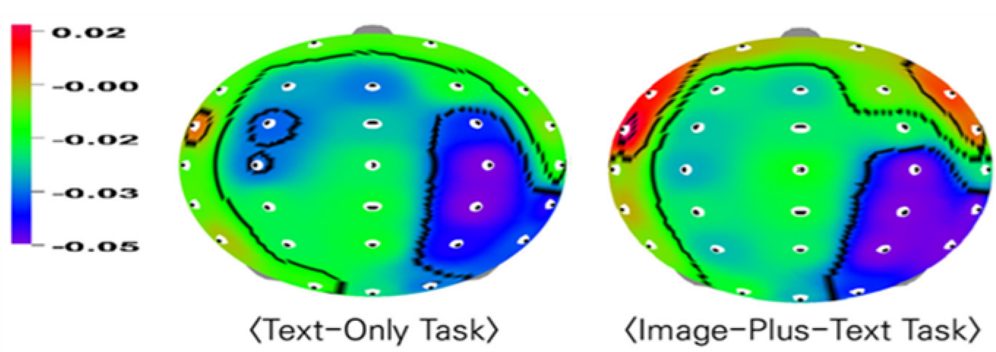

Fig. 7. Alpha band activation during fish species name memory

An independent-samples t test revealed a significant difference between task types in the frontal lobe (t=-3.801, *p*<.01), while a marginal difference was observed at the whole-brain level (t=-1.662, *p*=.097). Relatively higher alpha-band activation was observed in the image-plus-text condition compared to the text-only condition (Table 5). In addition, the effect size (Cohen's *d*) for the task-type difference at the whole-brain level was calculated and yielded a value of d≈0.06, indicating a very small effect size.

Table 5. Alpha relative power differences during fish species name memory

Brain region	N	Text-Only Task		Image-Plus-Text Task		t	p-value
		Mean	SD	Mean	SD		
Frontal lobe	576	-0.0183	0.0525	-0.0067	0.0512	-3.801	0.000***
Parietal lobe	432	-0.0324	0.0568	-0.0331	0.0464	0.210	0.834
Temporal lobe	288	-0.0191	0.0566	-0.0223	0.0547	0.684	0.494
Occipital lobe	144	-0.0227	0.0472	-0.0280	0.0382	1.051	0.294
Total	1440	-0.0231	0.0545	-0.0199	0.0506	-1.662	0.097*

***p<.01, *p<.1

Analysis of Alpha-Band Activation Differences According to Task Type During Fish Species Name Recall

Fig. 8 presents alpha-band activation during recall. Following the text-only task, alpha activation was highest in the frontal lobe (M=0.0292, SD=0.0423), followed by the parietal lobe (M=0.0158, SD=0.0475), the temporal lobe (M=0.0083, SD=0.0449), and the occipital lobe (M=−0.0178, SD=0.0425), with a whole-brain mean of 0.0163 (SD=0.0466). Following the image-plus-text task, alpha activation was highest in the frontal lobe (M=0.0285, SD=0.0394), followed by the temporal lobe (M=0.0083, SD=0.0441), the parietal lobe (M=0.0047, SD=0.0493), and the occipital lobe (M=−0.0236, SD=0.0416), with a whole-brain mean of 0.0121 (SD=0.0465).

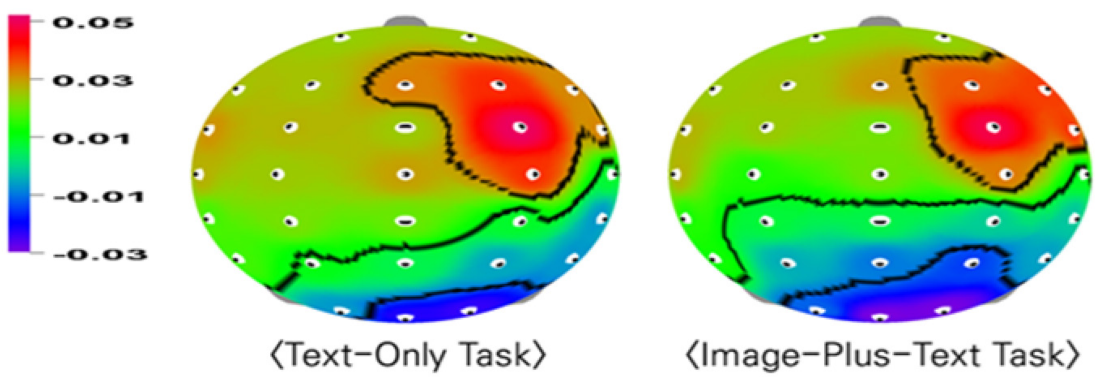

Fig. 8. Alpha band activation during fish species name recall

Independent-samples t-tests showed statistically significant between-condition differences in the parietal lobe (p<.01) and at the whole-brain level (p<.05), with lower alpha activation during recall in the image-plus-text condition (Table 6).

Table 6. Alpha relative power differences during fish species name recall

Brain region	N	Text-Only Task		Image-Plus-Text Task		t	p-value
		Mean	SD	Mean	SD		
Frontal lobe	576	0.0292	0.0423	0.0285	0.0394	0.280	0.779
Parietal lobe	432	0.0158	0.0475	0.0047	0.0493	3.371	0.001***
Temporal lobe	288	0.0083	0.0449	0.0083	0.0441	0.002	0.998
Occipital lobe	144	-0.0178	0.0425	-0.0236	0.0416	1.168	0.244
Total	1440	0.0163	0.0466	0.0121	0.0465	2.411	0.016**

***$p<.01$, **$p<.05$

Discussions

The present study investigated differences in learning performance and EEG relative power spectrum activation during the memory and recall of fish species names under two instructional conditions—text-only and image-plus-text—with the aim of exploring neurophysiological evidence related to effective instructional material design. Learning performance was assessed by the number of recalled fish species, while EEG data were concurrently collected to compute region-specific relative power spectra. Differences in neural activation between task conditions were examined and interpreted from an exploratory perspective.

First, participants showed a tendency to recall a greater number of fish species in the image-plus-text condition than in the text-only condition. This finding is broadly consistent with prior research suggesting that instructional materials integrating visual and verbal information can enhance learner engagement and learning outcomes (Moreno & Mayer, 1999; Ryu & Jung, 2013; Seufert et al., 2007). Previous studies have further reported that when textual information is meaningfully related to visual representations and presented in close spatial proximity, cognitive load may be reduced and learning efficiency improved. The relatively higher recall performance observed in the image-plus-text condition in the present study can therefore be theoretically linked to the complementary interaction between visual and verbal information proposed by multimedia learning principles and dual-coding theory.

However, the difference in recall performance between task conditions reached only a marginal level of statistical significance($p<.10$), and the corresponding effect size ($d\approx0.38$) fell within the small-to-moderate range. These results indicate that the findings should not be interpreted as strong causal or confirmatory evidence. Rather, they suggest that the image-plus-text presentation format may have the potential to positively influence learning performance, supporting an exploratory interpretation.

Second, with respect to theta-band activation, no significant differences across brain regions were observed between task conditions during the encoding phase. Given that theta activation has been shown to increase with heightened cognitive demands, task difficulty, and complex reasoning processes (Fairclough et al., 2005; Hutchison, 1996; Kim & Jang, 2001; Kim & Jung, 2015, 2016; Klimesch, 1995; Kwon et al., 2006), this null finding suggests that the two task formats elicited comparable levels of cognitive engagement during encoding. In other words, presenting text alongside related visual information in close spatial proximity did not substantially alter overall theta involvement during initial information encoding.

In contrast, during the recall phase, a marginal difference in theta-band activation was observed in the parietal lobe, with relatively higher theta activation in the image-plus-text condition. The parietal cortex is known to be involved in the integration and associative processing of sensory information and has been implicated in reading-related processes that combine letters into meaningful words (Jung, 2016; Kim, 2015; Kim & Jung, 2015). Moreover, increased theta activation has been associated with heightened attentional engagement and cognitively demanding processing. Accordingly, the elevated parietal theta activation observed during recall in the image-plus-text condition may reflect increased cognitive involvement as participants reconstructed previously learned fish species names through the integration of visual and verbal representations. Nevertheless, this difference was marginal ($p<.10$) and accompanied by a very small effect size (d≈0.12), warranting cautious interpretation. Rather than indicating a definitive enhancement of attentional engagement, this finding may be viewed as exploratory evidence that parallel processing of visual and verbal information, as proposed by dual-coding theory, can manifest differently at the neural level during recall.

Third, alpha-band activation exhibited distinct patterns across task conditions and learning phases. During the encoding phase, alpha activation in the frontal lobe was significantly higher in the image-plus-text condition. Alpha-band activation has been associated with cognitive stability and relaxed mental states, while frontal lobe is known to support evaluative and comparative processing (Fink et al., 2005; Jung & Yun, 2008; Kim & Jung, 2016). Taken together, the relatively elevated alpha activation of the frontal lobe observed in the image-plus-text condition suggests a reduction in cognitive tension during the encoding of textual information, reflecting a more stable cognitive state during the selection of information to be memorized. This interpretation is consistent with the notion that spatially integrated visual and verbal information can reduce extraneous cognitive load during encoding (Mayer & Moreno, 2002; Park et al., 2012).

During the recall phase, alpha activation in the parietal lobe was lower in the image-plus-text condition than in the text-only condition. Previous research has shown that alpha activation tends to decrease when sustained attention and increased cognitive effort are required (Fink et al., 2005; Sauseng et al., 2005). Given the role of the parietal lobe in sensory integration and word-level processing, reduced alpha activation in the parietal lobe during recall may indicate greater attentional resource allocation and cognitive effort as participants reconstructed learned information. From a cognitive load perspective, this pattern suggests that while extraneous cognitive load may be reduced during encoding through integrated materials, intrinsic processing demands may increase during recall as learners actively reconstruct meaning (Park et al., 2012).

In summary, the behavioral and EEG findings of the present study suggest that image-plus-text instructional materials may elicit cognitive and neurophysiological processing patterns distinct from those associated with text-only materials during the learning and recall of fish species names. Although the present results do not directly confirm prior theoretical claims, they provide limited neurophysiological evidence that integrated visual–verbal materials may support more efficient processing during encoding and greater attentional engagement during recall (Moreno & Mayer, 1999; Ryu & Jung, 2013; Seufert et al., 2007).

Conclusions and Implications

The purpose of the present study was to examine changes in EEG activation associated with two instructional task formats— a text-only condition and an image-plus-text condition in which pictorial information and related textual information were presented simultaneously—during the learning and recall of fish species names. To this end, an EEG-based experimental task was developed and administered to research participants. Behavioral performance across task types and differences in EEG relative power spectrum activation were analyzed and compared. The main findings of this study are summarized as follows.

First, behavioral analyses indicated that participants recalled an average of 2.42 fish species in the text-only condition, whereas they recalled an average of 2.77 fish species in the image-plus-text condition. This result suggests relatively higher recall performance when pictorial and textual information were presented together. However, this difference corresponded to a marginal level of statistical significance ($p<.10$), and the associated effect size fell within the small-to-moderate range. Accordingly, these findings should not be interpreted as definitive evidence that the image-plus-text format enhances learning outcomes. Rather, they suggest, from an exploratory perspective, that this presentation format may have the potential to exert a positive influence on learning performance.

Second, analyses of theta-band relative power spectrum activation revealed no significant differences between task conditions during the encoding phase of fish species names. This finding suggests that the two task formats elicited comparable levels of cognitive demand and engagement during encoding. However, during the recall phase, participants exhibited relatively higher theta-band activation in the parietal lobe in the image-plus-text condition compared to the text-only condition. Given that the parietal lobe is implicated in the integration and associative processing of sensory information, particularly in processes involving the combination of letters into meaningful words, this result may reflect a modest increase in cognitive engagement when participants reconstructed previously learned information. Nevertheless, this difference was marginal ($p<.10$) and accompanied by a very small effect size, indicating that caution is warranted when generalizing this result as a stable educational effect.

Third, analyses of alpha-band relative power spectrum activation demonstrated distinct patterns across task conditions and learning phases. During the encoding phase, relatively higher alpha-band activation was observed in the frontal lobe under the image-plus-text condition. Considering that the frontal lobe are associated with evaluative and selection processes, and that alpha-band activation is often linked to reduced mental tension and a more stable cognitive state, this pattern suggests that participants may have experienced lower cognitive strain when selecting information to be memorized under the image-plus-text condition. In contrast, during the recall phase, alpha-band activation in the parietal lobe was lower in the image-plus-text condition than in the text-only condition. Because reduced alpha activation has been associated with increased attentional allocation and cognitive effort, this finding suggests that participants devoted greater attentional resources when recalling information encoded through integrated visual and textual materials.

Taken together, these results indicate that learning with materials composed solely of textual information and learning with materials integrating pictorial and textual information may induce different cognitive and neurophysiological processing patterns. Specifically, participants appeared to experience reduced mental tension during information selection at the encoding stage and heightened attentional engagement during recall when learning with image-plus-text materials. These findings are consistent with prior research suggesting that instructional materials combining images and text—particularly when the two are meaningfully related and presented in close spatial proximity—can reduce extraneous cognitive load and enhance learning transfer by increasing intrinsic cognitive processing demands (Moreno & Mayer, 1999; Ryu & Jung, 2013; Seufert et al., 2007).

The present findings further offer several implications. Theta- and alpha-band EEG activation patterns are sensitive to changes in cognitive demand, mental tension, and attentional focus during learning tasks. Because these neural patterns are influenced by task characteristics, EEG-based measures can provide valuable insights into how external information is processed in the brain and how such processing relates to learning performance. Consequently, the results of this study may serve as foundational data for instructional design research aimed at developing more effective learning materials.

Despite these contributions, the present study has several limitations. First, the limited sample size constrained statistical power, and several findings remained at a marginal level of significance. Second, the generally small effect sizes observed across analyses limit the generalizability of the results as strong causal or confirmatory evidence. Third, although relative power spectrum measures are useful for exploring neurophysiological activation patterns during learning, they do not allow for direct inference regarding specific cognitive strategies or thought processes. Future research should therefore employ larger samples, incorporate diverse task types, and integrate additional behavioral and cognitive measures to more precisely elucidate the neurophysiological mechanisms underlying instructional material effectiveness.

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